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PRESSURE DROP IN FLEXIBLE METAL HOSES, BELLOWS, AND GIMBAL JOINTS

An Annotated Bibliography

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FOREWORD

This bibliography is the result of an extensive literature survey in an attempt to obtain detailed information, both empirical and theoretical, on the pressure drop occurring in corrugated hoses, bellows, and gimbal joints.

The sources surveyed in obtaining the information for this bibliography are as follows:

1. Defense Documentation Center
    a. Technical Abstract Bulletin
    b. Card Catalog
    c. Computer Card Search
2. Redstone Scientific Information Center
    a. Documents Section
        (1) Card Catalog
        (2) Scientific and Technical Aerospace Abstracts
        (3) Computer Tape Search
    b. Books Section
        (1) Card Catalog
    c. Periodicals Section
        (1) Engineering Index
        (2) Industrial Arts Index
        (3) Science and Technology Index
        (4) Bound Periodical Indexes
3. Battelle Memorial Institute, Mechanical Engineering Department
4. Interservice Data Exchange Program (I. D. E. P.)
5. V. S. M. F. and M. E. Catalog, and 20 flexible-hose manufacturers.

PRESSURE DROP IN FLEXIBLE METAL HOSES, BELLOWS, AND GIMBAL JOINTS

An Annotated Bibliography

1. Ambrose, Harry H., "The Effect of Character of Surface Roughness On Velocity Distribution and Boundary Resistance." The Engineering Experiment Station, The University of Tennessee College of Engineering, Knoxville, Tennessee, Project NS 715-102, Contract Nonr-811 (03), Office of Naval Research, Department of the Navy. 1955, AD69752.

The character of roughness of pipe walls has long been known to affect the velocity distribution and resistance characteristics of turbulent flow in the transition range between smooth-pipe flow and rough-pipe flow. The purpose of this study was to determine the specific effect of certain features of the roughness-element geometry by experimentally obtaining the velocity distribution and resistance functions for pipes with reproducible, artificially-roughened surfaces.

The surfaces investigated contained roughness elements which were cylindrical holes or projections, and which varied in size and in distribution. The depression-type roughness showed characteristics quite different from those of the projection-type roughness. For the range of values investigated, the depression-type roughness failed to exhibit the commonly assumed resistance function for rough-pipe flow. It was found possible, however, to generalize the resistance functions for the depression-type roughness by reference to the percent of surface area which was depressed. Generalized velocity distributions for this type of roughness showed a continuous trend with both the Reynolds number and the percent of depressed area.

The projection-type roughness and roughness composed of both projections and depressions yielded resistance coefficients that appeared to approach a constant value at high Reynolds number. The type of transition function depended upon the proximity of the projections to each other. Generalized velocity distributions showed dependence upon the Reynolds number as well as the roughness density.

2. Arrowhead Products, Division of Federal-Mogul-Bower Bearings, Inc., "Flexible Components for Pneumatic Ducting Systems." Technical Bulletin Number 516.

This bulletin explains the two basic approaches to the design of pneumatic ducting systems. These are:

(a) The "tension" type ducting system
(b) The "compression" type ducting system

Four types of flexible members are explained giving the advantages and disadvantages of each. These members are: (1) Plain bellows, (2) Tie rod joints, (3) Gimbal joints, and (4) Pin joints. Also included are pressure drop curves for these four type units for sizes 1 1/2, 2, 2 1/2, 3, and 3 1/2 inch diameter at 250 psig and 900°F.

3. Bowden, A. T. and J. C. Drumm, "Design and Testing of Large Gas Ducts." Proceedings of the Institution of Mechanical Engineers, Vol. 174, No. 3, 1960, pp 119-157.

This paper outlines some of the problems encountered in the design and testing of the large ducts associated with present-day gas-cooled nuclear reactors. Various ways of providing duct work with flexibility are analyzed, and it is shown that a design involving the use of a combination of tied expansion bellows and cascaded corners is the most economical way of meeting the need for high flexibility and low flow-pressure loss. The design of large tied expansion bellows is discussed, and an account is given of the tests carried out on a prototype of the bellows now being installed in the gas circuits of the Bradwell nuclear power station in Essex. A brief reference is made to the difficulties encountered in the development of large butterfly valves for reactor duct work, and performance figures are quoted for one of the valve designs that eventually proved successful under test.

4. Daniels, C. M., "Pressure Losses In Flexible Metal Tubing." Product Engineering, April 1956, p 223.

Friction coefficients and other pressure loss data are presented for annular and helical corrugated, flexible, metal hose at high flow rates ($Re=2 \times 10^6$). Included are graphs for flow rate (gpm of water) versus pressure drop (psi per foot of length) for 1, 2, 3, and 3 1/2 in. I. D. flexible metal hose, and Reynolds number versus Darcy-Weisbach friction coefficient for 2, 3, and 3 1/2 in. I. D. flexible metal hose.

5. Daniels, C. M., "Designing For Duct Flexibility With Bellows Joints." Machine Design, Oct. 15, 1959, pp 146-155.

This article presents an accumulation of the factors influencing the selection and application of the different types of metal bellows and gimbal joints.

6. Daniels, C. M. and R. E. Fenton, "Determining Pressure Drop In Flexible Metal Hose." Machine Design, Oct. 13, 1960, pp 195-198.

This article presents specific data, obtained by actual laboratory measurement, on pressure loss as a function of water volumetric flow for annular, helical, and helical-strip metal hose from 1/4 inch to 4 inches in diameter. Also, a generalized method for computing the pressure loss is presented.

7. Daniels, C. M. and R. E. Fenton, "Pressure Loss Factors for Internally Linked Bellows Joints." Machine Design, Sept. 14, 1961, pp 187-189.

This article presents experimentally obtained pressure loss factors for the chain-link type and gimbal-ring type internally linked bellows joints.

8. Daniels, C. M., "Bellows Design For Aerospace Vehicles." Rocketdyne Division, North American Aviation, Inc., Canoga Park, California, April 11, 1962, Rev. 3, Aug. 20, 1963.

This document is in the form of a specification. Its purpose is to describe the parameters influencing the design of bellows for use in aerospace cryogenic ducting. It was written at the request of the A-9D subcommittee in the SAE. The specification will be submitted to and reviewed by the subcommittee. After editing, it will become a part of the SAE Aeronautical Recommended Practice Bulletin entitled "Aerospace Vehicle Cryogenic Ducting." This specification contains a bibliography with 80 references on the different parameters influencing bellows design.

9. Goodloe, J. H. and H. Paul, "Friction Factors of Straight and Curved Flexible Metal Hoses as a Function of Reynolds Number." Cooling Section Memo No. 5. Guided Missile Development Group, Redstone Arsenal, Huntsville, Alabama, Aug. 12, 1952.

Flexible metal hoses of 1 1/2, 2, and 3-inch nominal inside diameter and 6 feet in length, manufactured by Chicago Metal Hose Corporation, were tested at 0°, 30°, 60°, 90°, and 180° angles of bend and at different air flows in order to determine the pressure losses and friction factors. The 3-inch hose was too short for a 180° bend test. The curvature, R/D (i.e., centerline radius of bend R over hose inside diameter D), was that recommended by the manufacturer. The 30° and 90° bends of the 2-inch hose were tested at other values of R/D to find the influence of the radius of bend. The Reynolds numbers of the tests ranged from 5×10^4 to 2.5×10^5 and do not include laminar flow.

At the lower Reynolds numbers, the friction factors for straight flexible hoses were found to be approximately two to three times larger than for commercial cast iron pipe of average roughness; the higher friction values were found to hold true for the smaller pipes. At the larger Reynolds numbers, the friction factors were found to be 3.5 to 7 times higher than for nonflexible pipes. Curved hoses had a consistently higher friction factor than straight hoses. With few exceptions, curved hoses showed an increase in friction factor with an increase in angle of bend. At 180° bends and for the same diameter, the friction factors were found to be 1.5 to 2 times higher than at 0° angle of bend. For the arrangements tested, the radius of bend appeared to be of slight influence.

10. Hawthorne, R. C., "Friction Factors For Flow Through Corrugated Hose and Bellows." Research and Development Division, Flexonics Division, Calumet and Helca, Inc., Jan 28, 1963.

See Reference 11.

11. Hawthorne, R. C. and H. C. von Helms, "Fluid Expansion Theory Computes Flow In Corrugated Hose." Product Engineering, June 10, 1963, pp 98-100

References 10 and 11 are essentially the same. These articles state that the corrugations in a hose or bellows may be considered as a series of uniformly spaced orifices. According to this assumption, the pressure drop would be caused by a series of flow expansions controlled by the corrugation pitch. Loss due to contraction is ignored, because such losses occur beyond the contraction and hence become a part of the subsequent expansion. In no case did the flow expansion approach the full corrugation height; hence, for the typical corrugation, height is not a variable in pressure loss calculations.

Two earlier concepts of pressure loss were discounted in these articles. These were: (1) that a hose behaves as an equivalent straight, smooth duct of three or four times the actual hose length, and (2) the assumption that the losses are induced in the valleys of the corrugations and in some way are related to corrugation height - specifically, relative roughness, e/D, where e is corrugation height and D is the equivalent diameter of the duct.

12. Lapera, Dominic and Franklin D. Yeaple, "Which Air-Flow Equation," Product Engineering, January 21, 1963, pp 47-52.

This article presents an evaluation of air-flow equations and their coefficients, and a simple way to make them interchangeable in system calculations.

13. Pachuta, Michael A., "A Study of Pressure Loss in Hose, Suction and Discharge Type." Report No. 1585-TR, Project 8-53-03-420, Petroleum Equipment Branch, Civil Engineering Dept., U. S. Army Engineer Research and Development Laboratories, Corps of Engineers, Ft. Belvoir, Virginia, July 14, 1959, AD226912.

This report presents data to be used for design purposes where knowledge of expected pressure losses in military hoseline is required. A study of two types - hardwall, rubber suction hose and collapsible discharge hose - is presented.

The report concludes that:

(a) Similar hose types from different manufacturers showed very small differences in pressure losses and conformed closely to the hypothetical chart which includes a safety factor.

(b) The hypothetical data presented on pressure losses and the nomograph adapted for ease of determination of losses can be utilized when constructing a military hoseline fuel system.

14. Webster, Marvin J. and Laurence R. Metcalf, "Friction Factors In Corrugated Metal Pipe." Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers. HY 9, September 1959, pp 35-67.

This paper discusses a study made to determine friction coefficients for flow in large corrugated metal pipe by measurement of head losses in pipes of 3, 5, and 7 feet in diameter. Also studied was velocity distribution for several discharges in each test pipe so that the results could be generalized to show the relationship between friction coefficients and absolute roughness. Data taken during the study are presented together with recommended values of friction and roughness coefficients.

15. Pepersack, F. J., "Pressure Losses in Flexible Metal Hose Utilized In Propulsion Fluid Systems of XSM-68B and SM-68B." Technical Memorandum Baltimore 25-10, Martin-Baltimore, September 1960.

This report was the result of an extensive testing program to obtain data to prepare graphs as required to predict the pressure losses in straight and curved sections of flexible metal hose utilized in propulsion fluid systems. Because of the convolutions used in its construction, the pressure loss through a given size straight flexible metal hose may be from 4 to 19 times the loss through an equivalent inside diameter, straight, missile quality, smooth tube. Tests with water and air in the turbulent flow region show multiplying factor (M. F., to be multiplied by the loss factor of an equivalent size smooth-bore tube to obtain pressure loss in corrugated hose) variation as follows:

(a) At Reynolds number up to 1×10^5 - slight gradual increase of low M. F.
(b) At Reynolds number 1×10^5 to 4×10^5 - greatest variation from low to highest M. F.
(c) At Reynolds number 4×10^5 and above - highest M. F. constant.

The loss through 90° bends of corrugated hose exhibits similiar characteristics to the loss through straight hose, i.e., a sudden increase occurs in the vicinity of Reynolds number of 1×10^5.

Recommended multiplying factors are presented for predicting the pressure loss in straight flexible metal hose or bellows 1/2 inch to 4 inches I.D. versus Reynolds number. Also presented are recommended pressure loss coefficients of 90° bends for flexible metal hose with R/D = 6 to 36 versus Reynolds number. Pressure loss data for bends include both friction loss and bend effect loss.

Recommended pressure loss correction factors for flexible metal hose bends other than 90° are included in the report.

Other information presented are schematics and photographs of test set-ups for the different types of test for both air and water, flow rate versus pressure drop for the three manufacturers' hose tested, and comparison data for smooth bore tubing.

16. Richard, L. A., "Report On Flow Tests With Bellows Expansion Joints." RSA A&SB-Flow Tests, Mechanical Laboratory, Aerodynamics and Structures Branch, Technical and Engineering Division, Redstone Arsenal, Alabama, November 1951.

Three types of bellows were considered. These were (1) Zellae Brothers and Johnson Co. with inner liner, (2) Zellae Brothers and Johnson Co. without inner liner, and (3) Chicago Metal Hose Co., which has no inner liner. For comparison purposes, the German-type bellows was used with and without inner liner, under the same flow conditions used in testing the domestic bellows. The test data with a graph of flow rate versus flow pressure are presented.

17. Waters, E. D., "Effect of Wire Wraps on Pressure Drop for Axial Turbulent Flow Through Rod Bundles." HW-65173 Rev., UC-38, Engineering and Equipment (TID-4500, 20th Ed.) Engineering Development, Reactor and Fuels Laboratory, Hanford Atomic Products Operation, Richland, Washington. Contract No. AT (45-1)-1350 between the Atomic Energy Commission and General Electric Co. June 1963.

Pressure drop has been determined experimentally for adiabatic axial flow through rod bundle assemblies in a Reynolds number range from approximately 2×10^4 to 2×10^5. Bundles of seven and nineteen rods were used in round pipes. Using seven-rod bundle assemblies, data were obtained to show pressure as a function of the pitch of wires wrapped spirally around each of the six outer rods. Wire wrap pitch was varied from 2 to 18 inches. Experimental data are correlated in terms of friction factors for nonwrapped bundles and drag coefficients for the wire wraps. Pressure drops calculated from these relations generally agree within $\pm$ 10 percent of measured drops. Experimental friction factor values are compared with the Moody smooth tube values.